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# Regional simulations of urban metabolism and climate with WRF-ACASA


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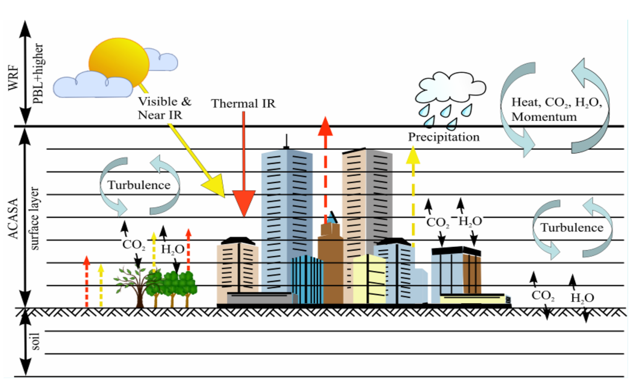
## ABSTRACT

The number of urban metabolism studies has increased in recent years, due to the important impact that energy, water and carbon exchange over urban areas have on climate change. Urban modeling is therefore crucial in the future design and management of cities. This study presents the University of California, Davis Advanced Canopy Atmosphere Soil Algorithm (ACASA) model coupled to the Weather Research and Forecasting (WRF) mesoscale model to simulate urban fluxes at a horizontal resolution of 600 meters for an urban area in Helsinki, Finland of roughly 20 km by 20 km. As part of the European Project “BRIDGE”, these regional simulations were used in combination with remotely sensed data to provide constraints on the land surface types and the exchange of carbon and energy fluxes from urban centers. Surface-atmosphere exchanges of mass and energy were simulated using ACASA. The WRF-ACASA model was used to simulate a regional domain that allows for better evolution of the urban atmosphere exchange: we used a sequence of 5 nested domains with feedback for WRF-ACASA (◎x = 48.6, 16.4, 5.2, 1.8, and 0.6 km) using NNRP reanalysis data in combination with CLC land cover data.

Our results show that the model performed well compared with the observations both for the surface energy fluxes as well as the surface carbon exchange. The model can generally account for 45-72% of half-hourly variations of observed fluxes. Generally the partitioning of energy fluxes was on par with other urban model performances. On a biweekly time scale we compared the average diurnal course of sensible, latent, and CO2 fluxes (QH, QE and FC) from the model against observations. The model was able to resolve 91-92% of the variation of observed fluxes on this aggregate scale with a slope of the linear regression of 1.19, 0.92 and 0.95 for QH, QE and FC respectively. Simulations yielded spatially consistent results according to land use distribution and location of the urban center.


## MODELLING

The off-line multilayer model ACASA (Pyles et al., 2000; Marras et al., 2011) (Fig. 2) has been applied by CMCC at Helsinki and Florence case studies, at local scale (Marras et al., in prep), and at regional scale using the coupled model WRF-ACASA (Figs. on the right) to estimate the exchanges of moisture, carbon dioxide, radiation, heat, momentum, and other quantities. Figure 1 (below) is a cartoon schematic showing this coupling & its main physical aspects




## Regional urban metabolism

WRF-ACASA simulations of urban mass and energy fluxes were conducted over two different urban regions: a high latitude city, Helsinki (Finland) and an historic European city, Florence (Italy). Helsinki is characterized by recent, rapid urbanization that requires a substantial amount of energy for heating, while Florence has far older, thicker buildings, with higher amounts of thermal inertia in the walls. Domains for Helsinki are shown on the left and center, Florence on the right hand side:

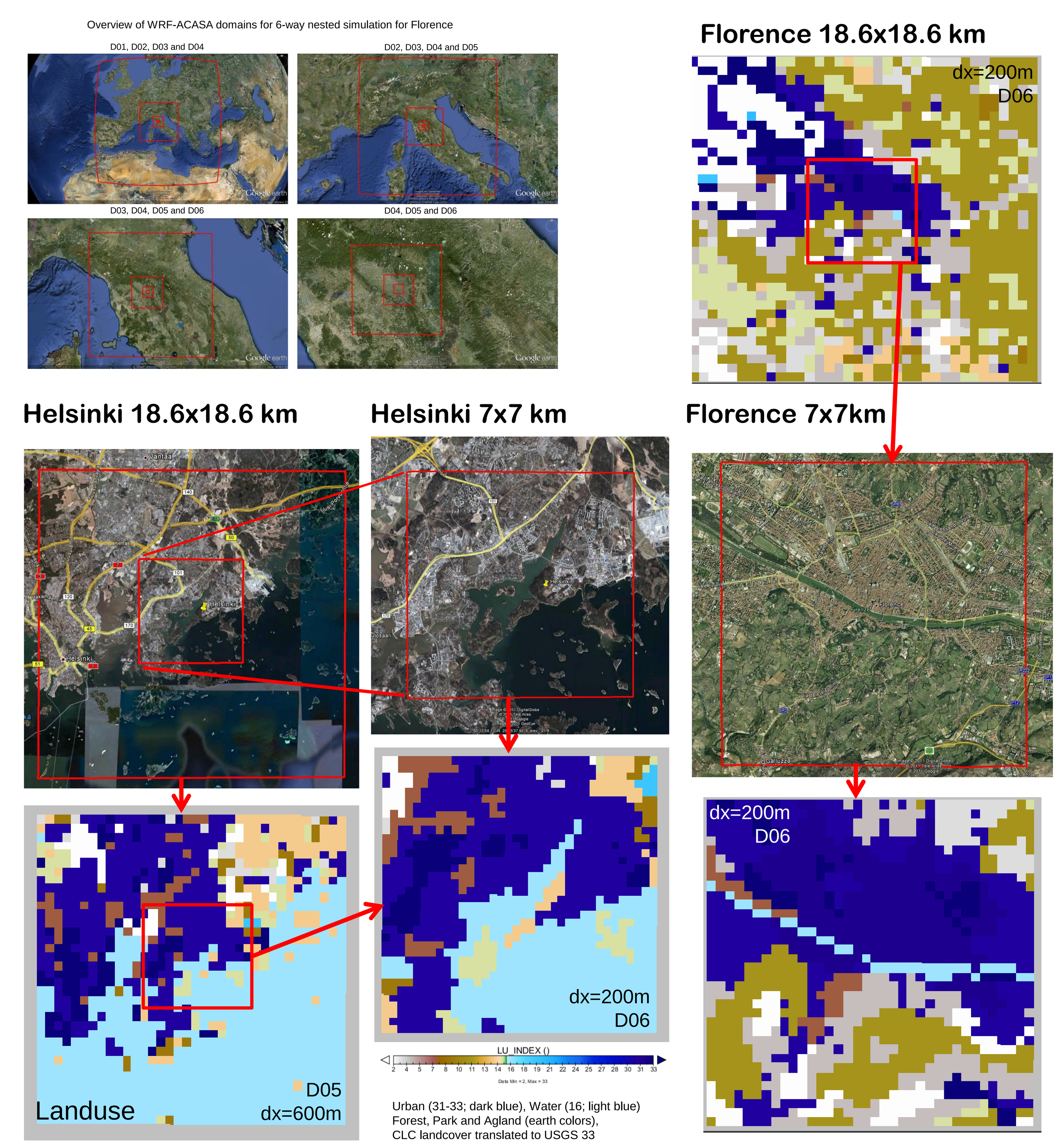



**Fig. 2**: High resolution domains d05 (Helsinki) and d06 (Helsinki and Florence) for the fully nested WRF-ACASA simulations using 100 meter resolution Corine Land Cover (CLC 2000)

**Helsinki, Finland**
**inner domain (d06): 7x7 km, dx=200m**
**outer domain (d05): 18.6x18.6 km, dx=600m**

**Florence, Italy**
**inner domain(d06): 7x7 km, dx=200m**
**outer domain (d05): 18.6x18.6 km, dx=600m**

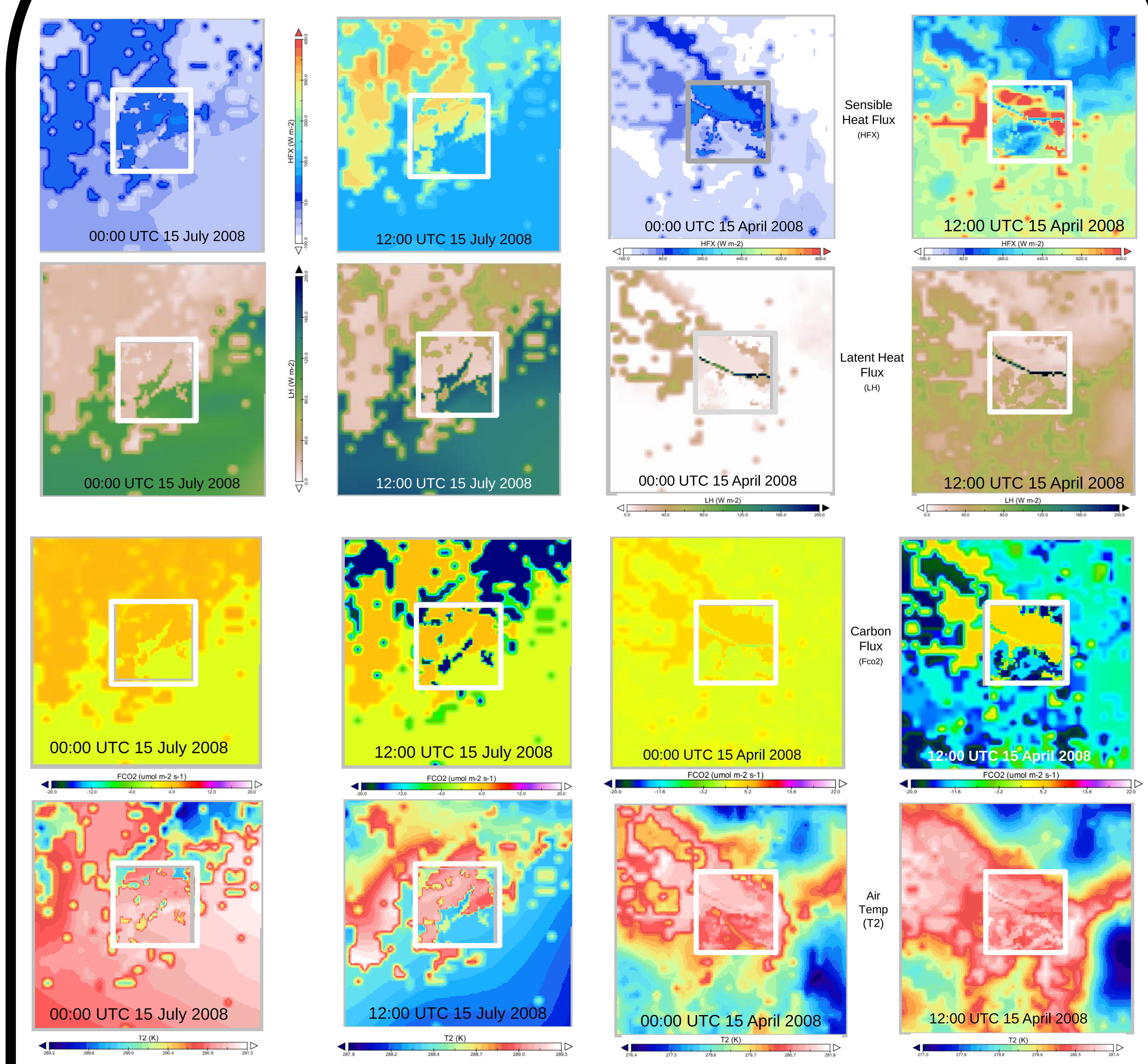
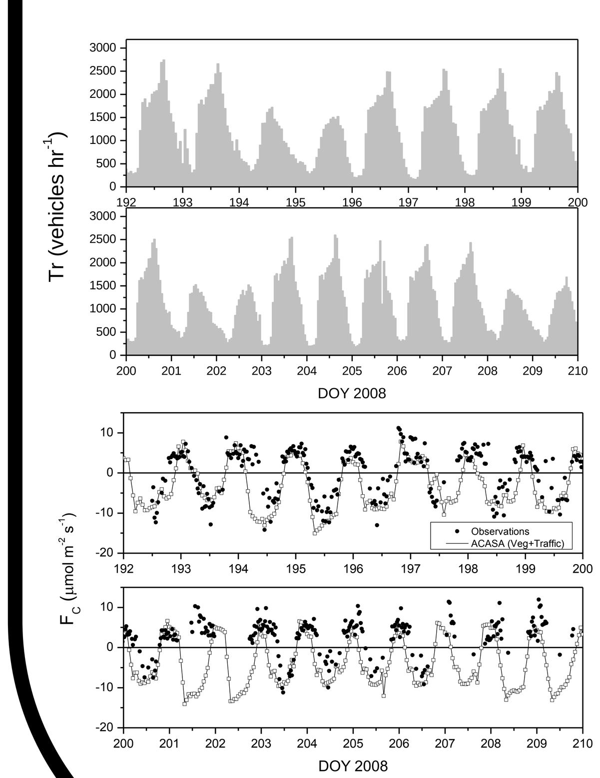
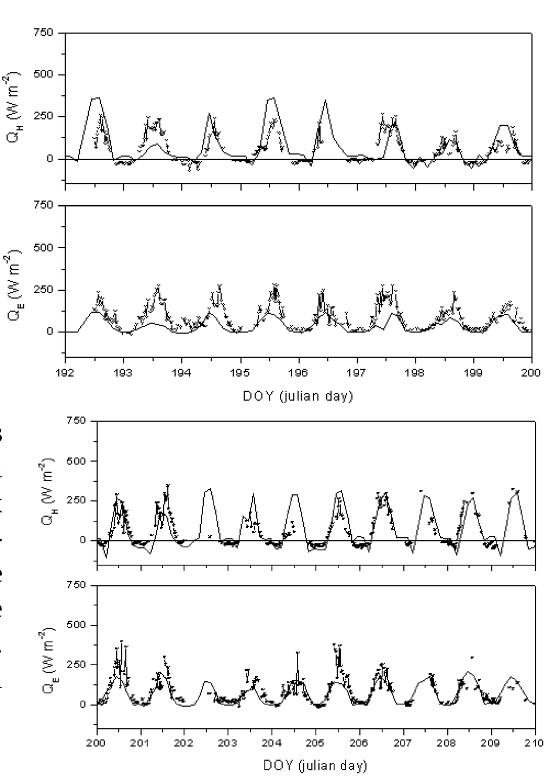



**Fig. 3:** Fully nested WRF-ACASA simulations (2008) using 100 meter resolution Corine Land Cover (CLC 2000), shown are results for July (Helsinki) and April (Florence) respectively.
**Left hand side**: Surface fluxes and temperature fields for Helsinki (eight panels total). Left column represents 00:00 UTC (night), and the right column represents 12:00 UTC (midday) values. From top to bottom: Sensible heat flux density (HFX) , latent heat flux density (LH), CO2 flux density (FCO2), and 2-meter air temperature (T2). White rectangle indicates approximate boundary between the innermost (200m gridded) domain and the adjacent outer domain (600m grid). The simulation invoked six nested concentric domains, the outermost domain encompassing the European continent on 48km grid . Urban heat island effects are apparent in the temperature field, while H and LE vary widely both day and night within each domain, depending on land use & local meteorological effects. Values are within range of observations (full analyses pending).
**Right hand side**: Surface fluxes and temperature fields for Florence (eight panels total). Left column represents 00:00 UTC (night), and the right column represents 12:00 UTC (midday) values. From top to bottom: Sensible heat flux density (HFX) , latent heat flux density (LH), CO2 flux density (FCO2), and 2-meter air temperature (T2). fields here as well indicate high dependence on WRF forcings and microenvironment on land use. The stippled feature with high value for LH are points representing enhanced evaporation over the Arno river, 200m gridded from city air (relatively dry) moving over the water. Values of T2 can vary by several degrees C within the areas.




The time series plots to the left shows hourly traffic rate (top) and measured (flux tower) and modeled (WRF_ACASA tower pixel) carbon flux for Helsinki (bottom) for the period of July 19th through July 29th 2008

The two right hand side plots show the average diurnal course of measured (flux tower) and modeled (WRF-ACASA tower pixel) surface fluxes of $Q_H$, $Q_E$) for the period of DOY 192-210, 2008. Error bars indicate standard deviations.



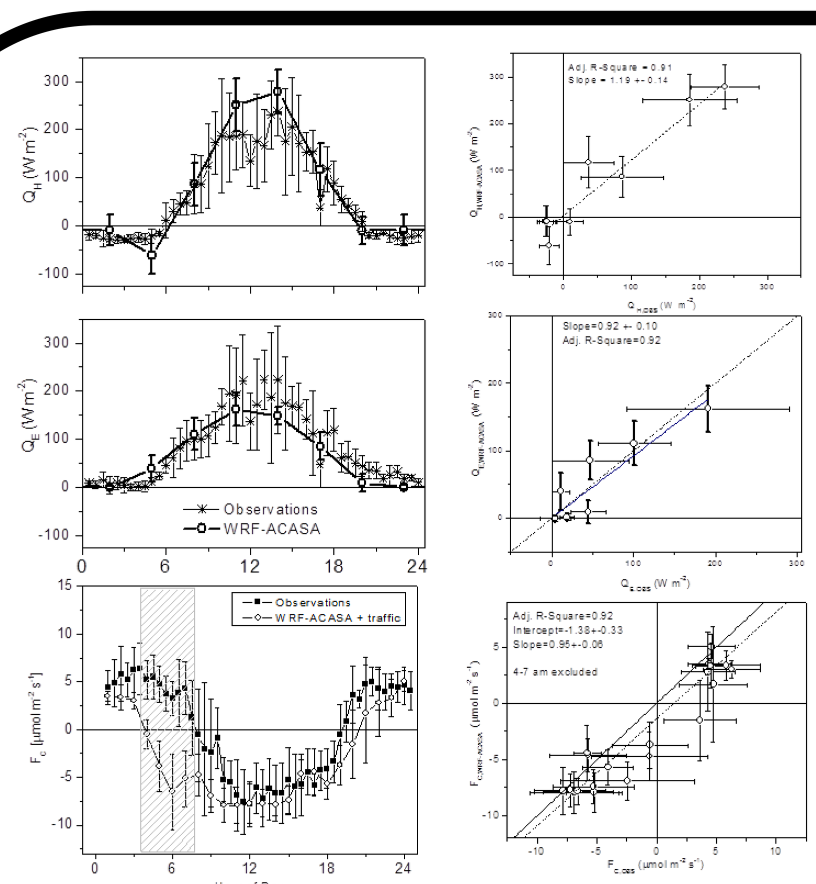




**Figure 7**: Scatter plot of modeled (WRF-ACASA tower pixel) versus measured (flux tower) time series data of $F_C$ for the period of DOY 192-210, 2008.Upper panel shows all data, lower panel shows data filtered for wind direction and without early morning values.

**Figure 8**: Scatter plot of modeled (WRF-ACASA tower pixel) versus measured (flux tower) of $Q_H$, $Q_E$ and $F_C$ from the average diurnal course for the period of DOY 192-210, 2008.Errors shown for the measurements and model estimates are the standard deviations. The linear regression model was weighted by the x and y errors.

### 5. Conclusions.

The WRF-ACASA model was tested for the simulation of regional urban surface exchange over Helsinki, Finland. The model simulations were validated against eddy covariance observations measured at an urban tower operated by the University of Helsinki [35,36]. WRF-ACASA results compared well with observations both for the surface energy fluxes as well as the surface carbon exchange once traffic emissions were taken into account. The model generally accounts for 45-72% of half-hourly variations of observed fluxes. The $F_C$ model results were the more challenging because wind direction changes affected $F_C$, which often varied from daytime sink to source and vice versa. Jarvi et al. [36] explain this variability well by differentiating the results for the multi-year time series into three different sectors. Excluding early morning hours (4 am-7 am) improved model to observation comparison and, with further selecting a narrow sector for optimum fetch (wind direction of 200-240 degrees only), the model can explain 67% of variation of the observed fluxes. Generally the partitioning of energy fluxes was on par with other urban model performances [42,43,44] but ACASA adds the unique capability to provide estimates of combined biogenic and anthropogenic carbon exchange when applied to urban systems.
On a biweekly time scale, we compared the average diurnal course of $Q_H$, $Q_E$ and $F_C$ of the model against observations. The model was able to resolve 91-92% of the variation of observed fluxes on this aggregate scale with slopes of the linear regression of 1.19, 0.92 and 0.95 for $Q_H$, $Q_E$, and $F_C$, respectively. There was a slight overestimation of carbon uptake by the model, but more realistic values of LAI over urban areas might correct this issue in future simulations.
The model performed very well in representing average conditions over the investigated period and reasonably well for hourly variations. This study represents the first attempt to simulate regional urban exchange, and it shows great promise for applying this scheme successfully in future applications ranging from accurate estimation of urban evapotranspiration, carbon exchange, urban planning to climate change mitigation.